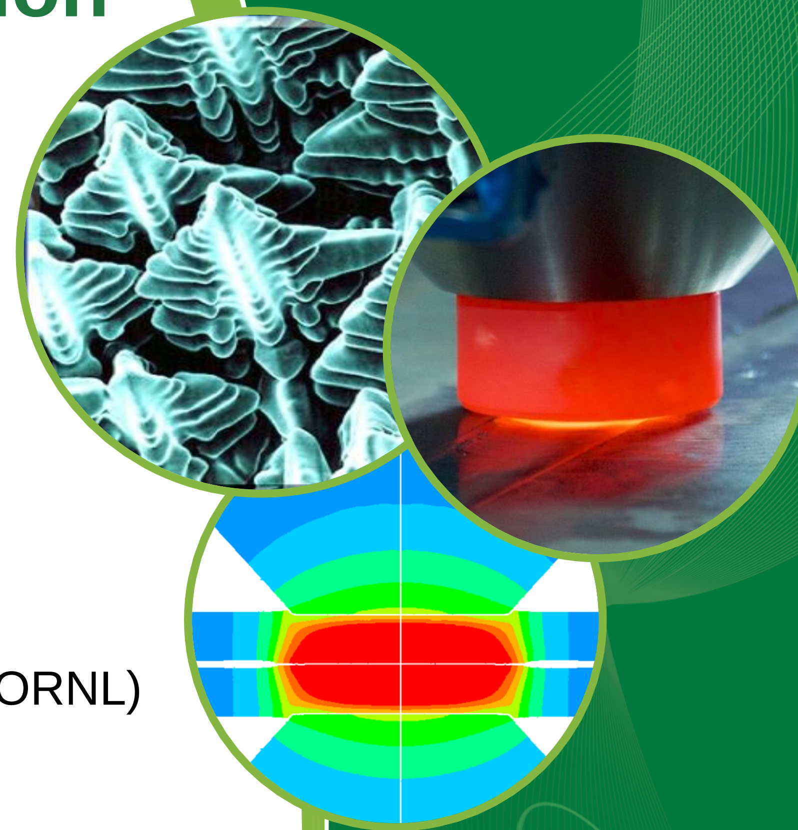
# Non-Destructive Inspection of Al-Steel Weld Bond



2019 DOE Vehicle Technology Office

Annual Merit Review Presentation

Jian Chen (Presenter) and Zhili Feng (PI) (ORNL)

Blair Carlson, Megan McGovern, Amberlee Haselhuhn and Teresa Rinker (GM)

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**Project ID: MAT154**

Oak Ridge National Laboratory

# Overview

## Timeline

- Start: Oct 1, 2017
- End: April, 2019
- Percent complete: 100%

## Barriers

- Barriers addressed
  - Non-destructive techniques for the evaluation of the integrity of aluminum and aluminum-steel joints made with lightweight materials*.

** Refer to U.S. DRIVE MTT Roadmap, section 5.1*

## Budget

- Total project funding
  - DOE share: $200K
  - Industry in-kind share: $200K
- Funding for FY18: $400K

## Partners

- Interactions / collaborations
  - GM
- Project lead
  - Oak Ridge National Laboratory

# Relevance

- Auto industry increasingly relies on multi-material strategy to balance the performance, fuel efficiency and cost of auto body structures.
- Industry is in a critical need of an effective nondestructive evaluation (NDE) tool to inspect the quality of dissimilar material joints.
  - Today industry primarily relies on periodic destructive testing which is labor and cost intensive.
  - Conventional NDE methods (e.g. ultrasound) cannot be used in mass production environment.
  - Infrared (IR) thermography is a non-contact and nonintrusive NDE method with potential applications.

Resistance spot weld coupons made with GM multi-ring domed (MRD) electrodes

# Milestones

| Month/Year | Milestone or Go/No-Go Decision |
|---|---|
| April -18 | Weld sample preparation (**Completed**) |
| April -18 | NDE measurements and data collection (**Completed**) |
| Sep -19 | Destructive evaluation(**Completed**) |
| Feb -19 | Development of NDE algorithms and data analysis(**Completed**) |
| March -19 | Comparison and down selection of different NDE approaches (**Completed**) |
| April -19 | System validation (**Completed**) |

# Approach

- A large set of (1) steel-steel, (2) aluminum-aluminum and (3) aluminum-steels resistance spot welded coupons were produced at GM.
  - It includes 7 sets of material stack-ups. Each stack-up contains 5 target weld nugget size
- Three different IR based NDE approaches were explored:
  - (1) inline (real-time) IR images
  - (2) offline (post-weld) IR measurement with pulsed flash lamp heating
  - (3) offline (post-weld) IR measurement with induction heating method
- IR NDE algorithms were developed to predict weld nugget dimension
  - The unknown surface emissivity issue needs to be considered
- Welds were destructively characterized to determine actual weld nugget dimension.
- Different IR NDE approaches were evaluated and compared based on the actual measurements.

# Accomplishment: Testing Matrix

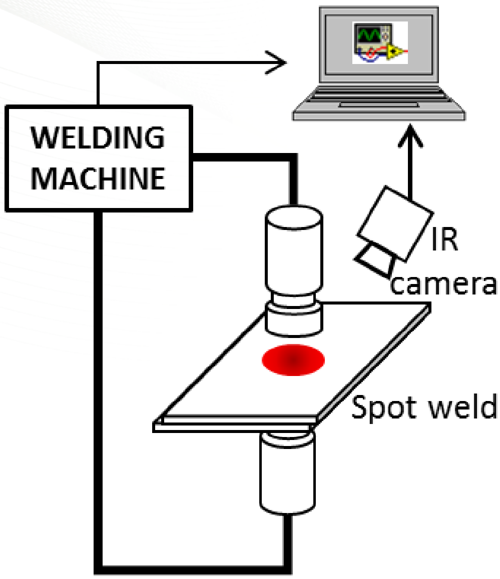
| Stack-Up | | Electrodes |
|---|---|---|
| Steel-steel welds | 1.0mm HDG LCS – 1.0mm HDG LCS | 6006 Ballnose |
| | 1.0mm HDG LCS – 1.0mm HDG LCS | 6006 MRD* |
| | 2.0mm HDG LCS – 2.0mm HDG LCS | 6148 MRD* |
| Aluminum-aluminum welds | 0.8mm x626 Al – 0.8mm x626 Al | 6006 MRD* |
| | 1.2mm 6022 Al – 1.0mm x610 Al | 6148 MRD* |
| Aluminum-steel welds | 0.8mm x626 Al – 1.0mm HDG LCS | 6006 Hybrid (MRD*/Ballnose) |
| | 1.2mm 6022 Al – 2.0mm HDG LCS | 6148 MRD* |

**MRD – multi-ring domed resistance spot welds*

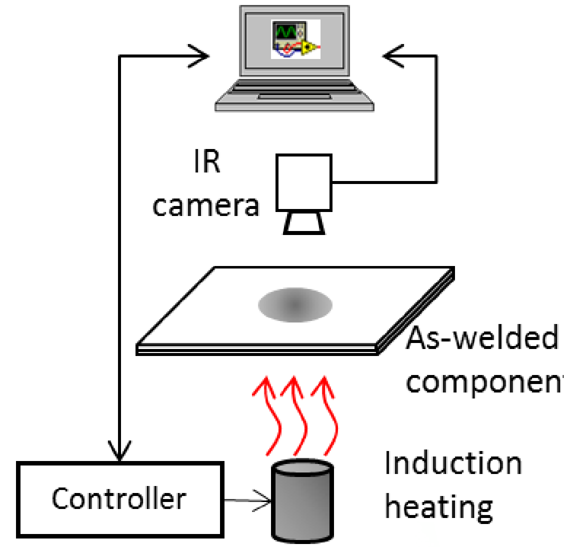
Each stack-up of resistance spot welds has 5 different welding conditions corresponding to 5 expected nugget sizes. Each welding condition has multiple repeats.

# Accomplishment: IR NDE Approaches

## Inline

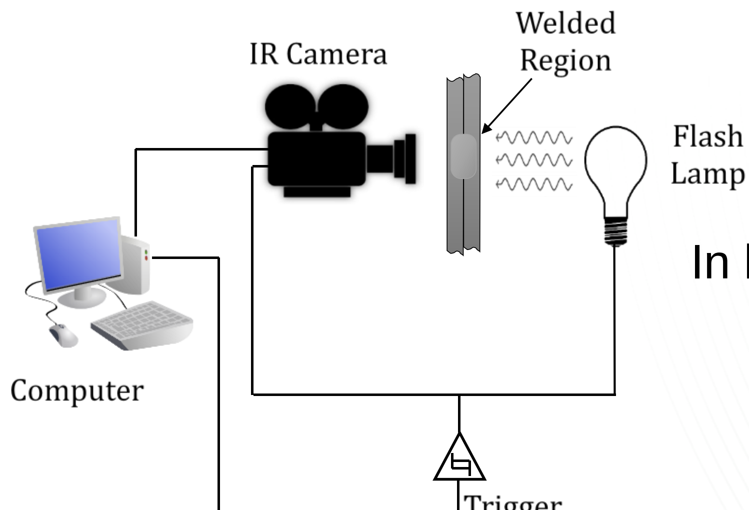



## Offline (induction heating)




2~3s

## Offline (flashlamp heating)




In less than 1ms

# Accomplishment: Algorithm Development

- Critical issue: unknown surface condition
  - IR camera measures the IR intensity. Variations in surface condition (i.e. emissivity) cause unreliable temperature reading

$$\boxed{T \approx f(W_{tot}, \varepsilon)}$$

Temperature

Measured IR intensity

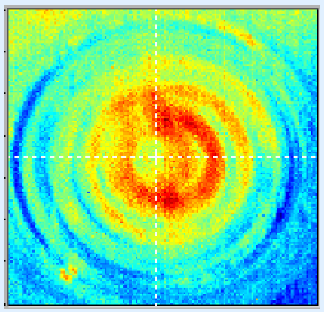
Surface emissivity (unknown)

- We have developed novel data analysis algorithms to extract <u>emissivity-independent</u> thermal signatures that can be correlated to weld quality
  - Algorithms are based on relative temporal and spatial changes of the IR intensity map

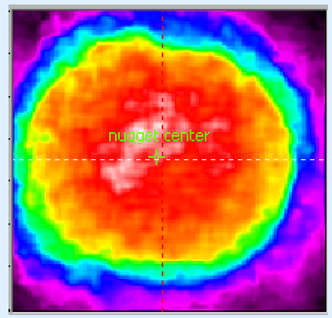
# Accomplishment: Algorithm Development (Cont'd)

## Establishment of weld quality database

Raw IR intensity data



Thermal signature

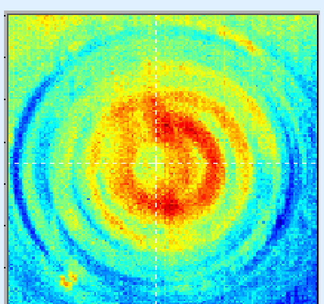



Measurement data

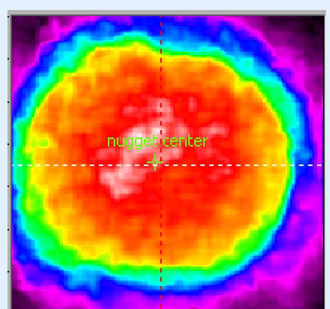
Weld quality database

## Prediction of weld quality

Raw IR intensity data



Thermal signature



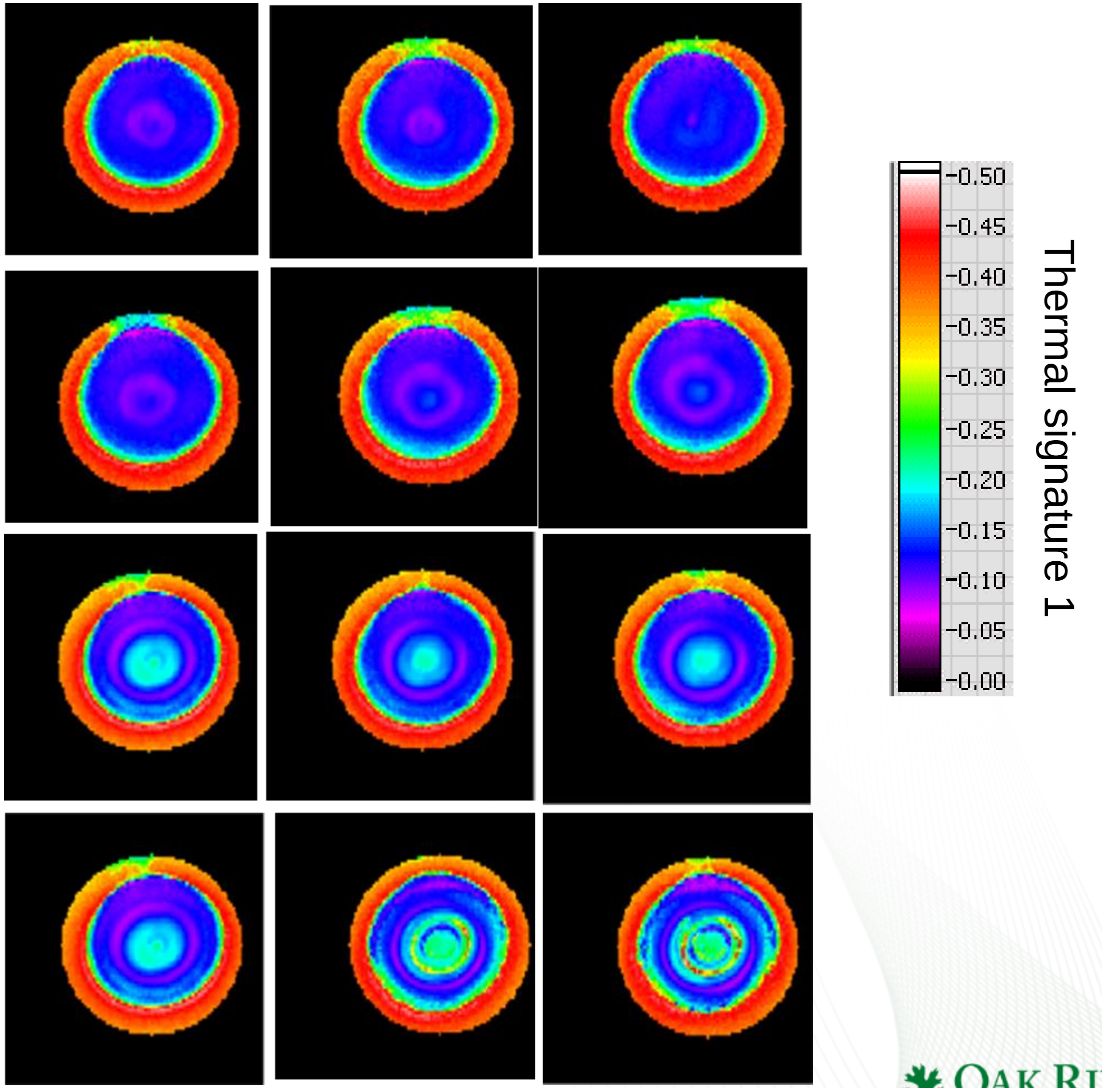

Weld quality database

Predicted weld quality

# Accomplishment: Thermal Signature

Thermal signature extracted from *inline* IR images

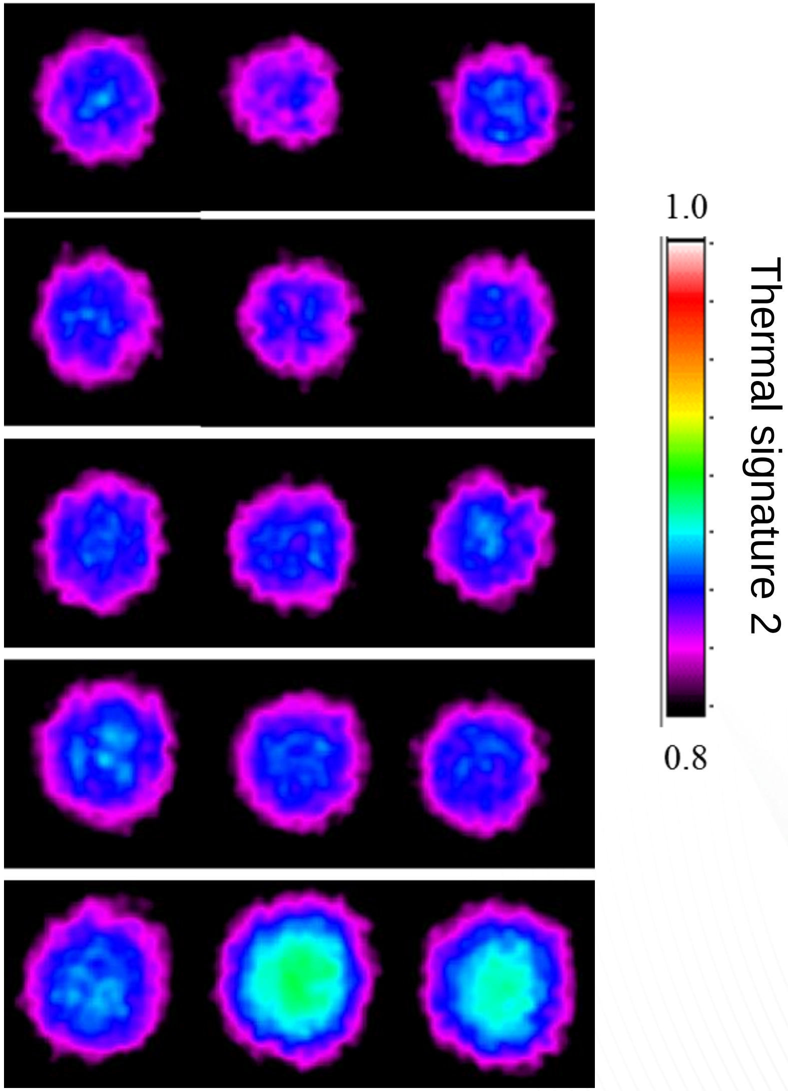
Increasing welding current
(3 welds at each current level)



# Accomplishment: Thermal Signature (Cont'd)

Thermal signature extracted from *offline* IR images (induction heating)

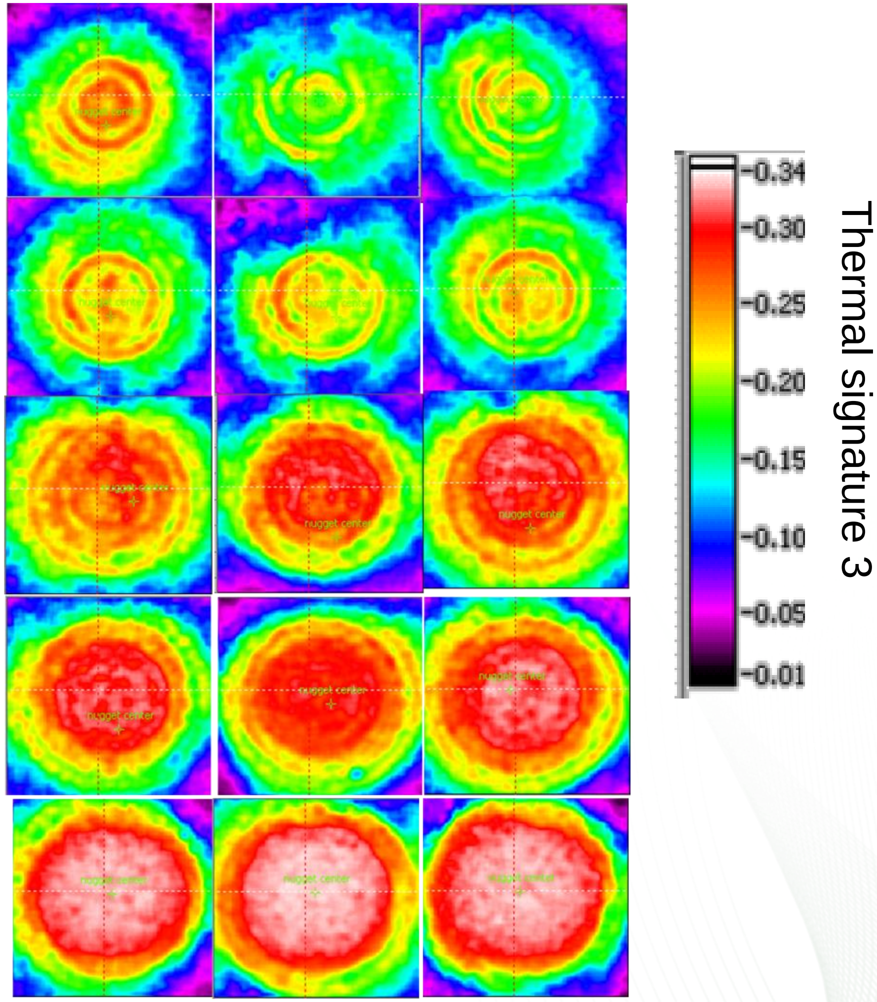
Increasing welding current
(3 welds at each current level)



# Accomplishment: Thermal Signature (Cont'd)

Thermal signature extracted from *offline* IR images (flash lamp heating)

Increasing welding current
(3 welds at each current level)



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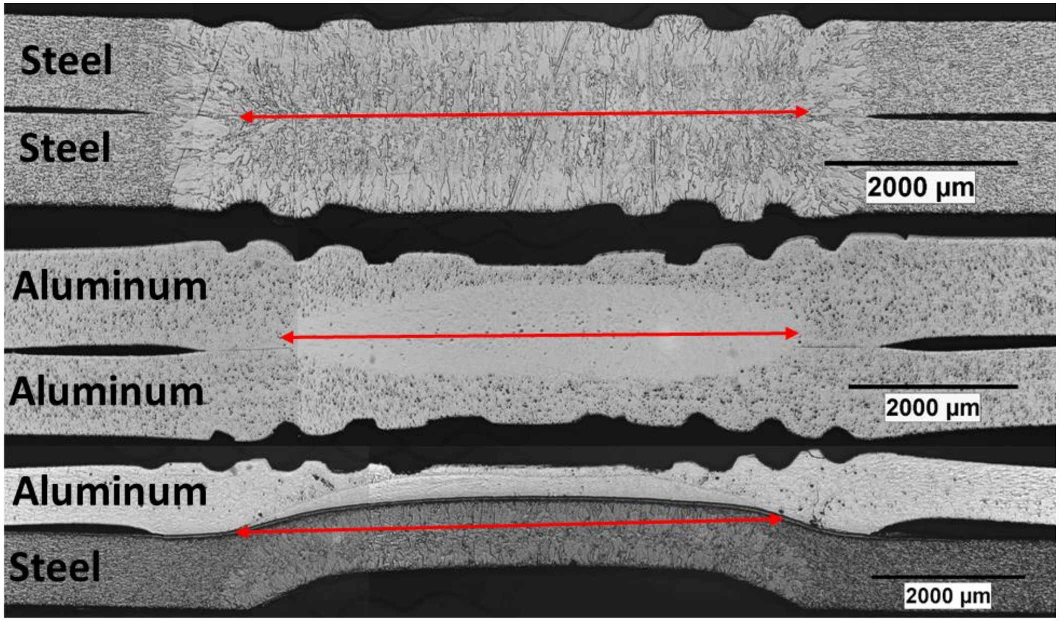
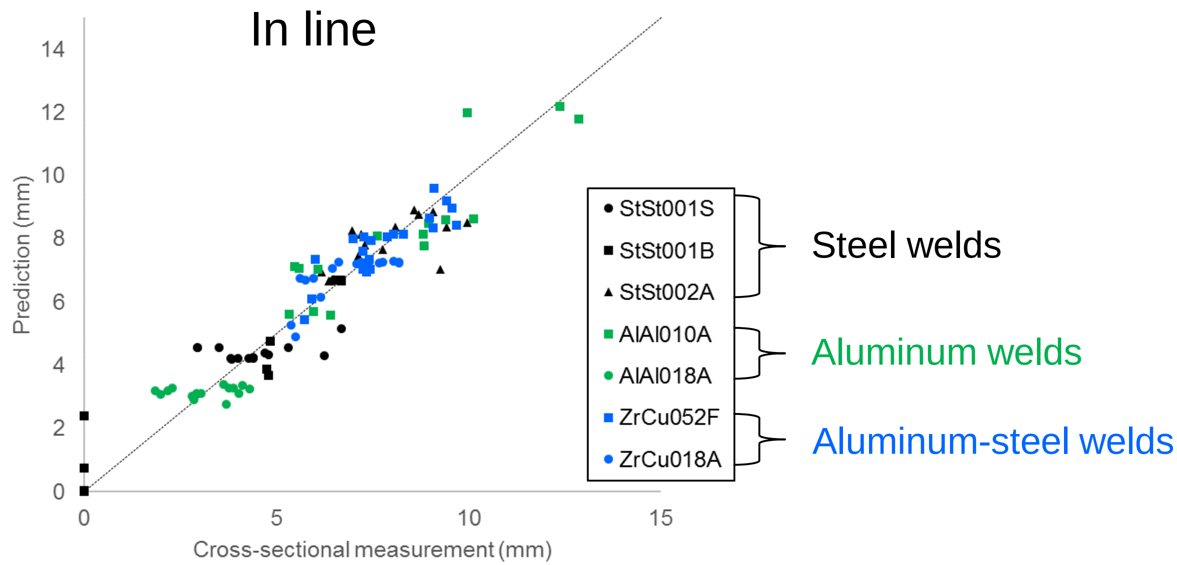
# Accomplishment: Destructive Measurements

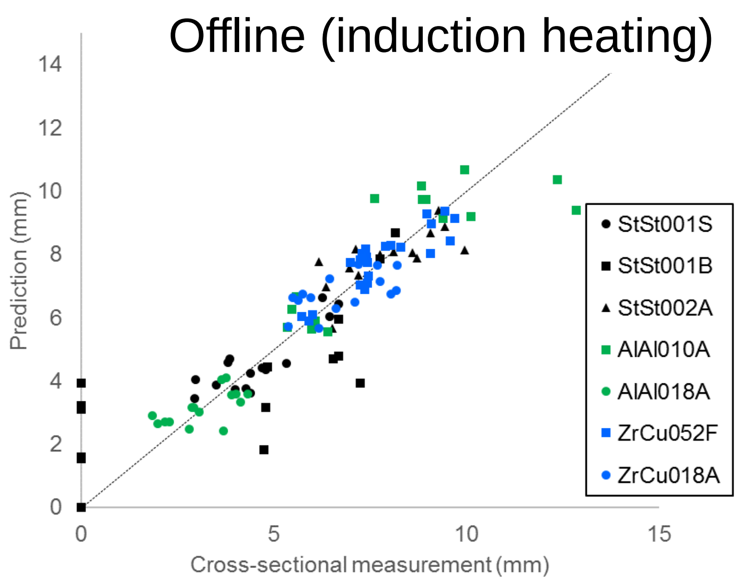
Actual nugget size was measured through cross-sectional macrographs

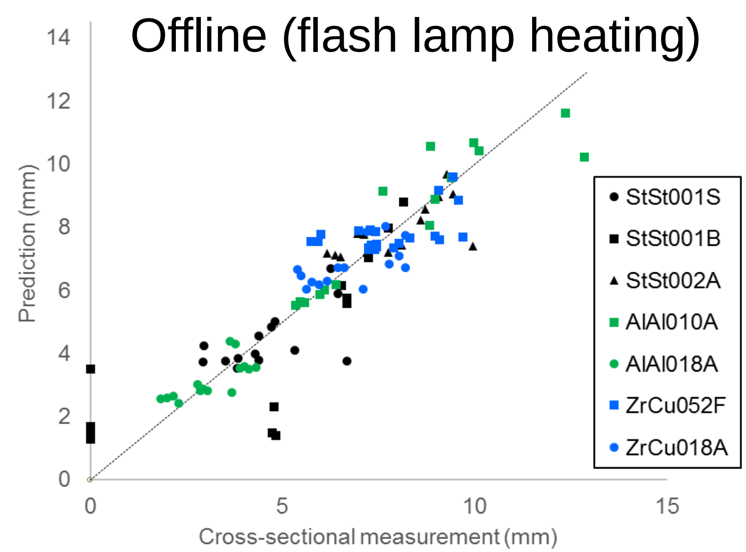



130 welds were cross-sectioned to validate the predicted nugget diameter by different IR NDE methods

# Accomplishment: Weld Nugget Prediction vs. Measurement



# Response to Previous Year Reviewers' Comments

- This project was not previously reviewed



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# Collaboration and Industry Participation

- Extensively and closely worked with the industry (GM)
  - All welds were made at GM
  - IR images (inline, offline induction and offline flash lamp) were collected on site by ORNL and GM
  - NDE algorithms were developed together by ORNL and GM
  - Weld samples were cross-sectioned and analyzed by GM

# Remaining Challenges

- Inline IR NDE method
  - Thermal signature is sensitive to welding conditions
- Offline (flash heating) IR NDE method
  - Low heat input and low signal-noise ratio
  - Relatively challenging to measure thick stack-ups
- Offline (induction heating) IR NDE method
  - Low electromagnetic coupling with aluminum
- Explore and develop improved IR monitor signal to weld quality correlations

# Summary

- An innovative weld quality non-destructive evaluation (NDE) technology using infrared (IR) thermography
  - Including innovations in both hardware setup and software to correlate IR signals to quality (thermal signature)
  - Addressing a major need and significant market in auto industry
    - Capable for both real-time online and post-weld online/offline NDE
    - Applicable to high-volume mass production environment
    - Enabling increased use of high-strength lightweight materials in auto-body structures to meet the government mandates for fuel efficiency and crashworthiness
    - Affordable: $25-35K/unit
- Funded by DOE EERE Vehicle Technologies Office, with strong auto industry supports (A/SP, ArcelorMittal, Ford, GM, Cosma)